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DESCENT-RATE CUING FOR CARRIER LANDINGS: EFFECTS OF DISPLAY GAIN, DISPLAY NOISE AND AIRCRAFT TYPE

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Interim Report TR-81-015
1 May 1980 - 30 November 1981

Prepared for:

NAVAL TRAINING EQUIPMENT CENTER
Orlando, Florida 32813

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Two studies are reported concerning the utility of modifying a conventional Fresnel Lens Optical Landing System (FLOLS) to include variable-length vertical light arrays, or arrows, in order to provide descent-rate information to pilots making carrier landings.

In the first study, the Descent-Rate Cuing (DRC) algorithm incorporated an angular gain to provide glideslope displacement information. The DRC

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system did not significantly improve glideslope tracking performance. Lineup performance was not adversely affected. The effects of aircraft type and noise on the DRC were also examined.

In the second study, the DRC algorithm incorporated a modified linear gain to provide glideslope displacement information. The DRC system consistently reduced glideslope error throughout the approach.

Comparison of the data and previous research suggests that a DRC system incorporating a linear gain can produce a strong and consistent improvement in glideslope control in carrier landings.

PREFACE

The authors would like to acknowledge several people who assisted with the research described in this report.

The following personnel associated with the VTRS program provided technical support: Walter S. Chambers, Patricia Daoust and Edward Holler of the Naval Training Equipment Center (Code N-732); Brian Nelson and Daniel Westra of Canyon Research Group, Inc.; Clark Getz of Appli-Mation, Inc., and Jack Davis and Karen Thomley of the University of Central Florida.

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BACKGROUND

The Fresnel Lens Optical Landing System (FLOLS) provides primary glide-slope displacement information for a carrier approach to landing. It consists of light sources behind five vertically stacked Fresnel lenses that are situated between two horizontal light arrays known as the datum bars. The array of lenses and lamps provides a virtual image which appears to the pilot as a single light located 150 ft. behind the datum bars. This light is known as the meatball. The meatball is visible to the pilot through the center lens when he is within 9.5 minutes of arc of the glide-slope and is seen as level with the datum bars. As the aircraft moves more than 9.5 minutes of arc above or below the glideslope, the meatball is seen through higher or lower Fresnel lenses to give the appearance of moving vertically above or below the line of the datum bars (Figure 1).

For a carrier approach the pilot attempts to follow a designated glide-slope (usually 3.5^{o}), by keeping the meatball level with the datum bars, so that a hook attached to the tail of the aircraft will contact the landing deck midway between the second and third of four arrestment cables, known as wires. The wires are stretched across the landing deck at different distances from the ramp (threshold of the landing deck). Under the aircraft's momentum the hook travels forward to snag the third wire for a trap (arrested landing). The first or second wire may be caught on a low approach, and the fourth on a high approach. Very low approaches can result in a ramp strike (collision with the stern of the carrier) while high approaches can result in a bolter (a missed approach because of touch-down beyond the wire arrestment area).

The displacement information provided by the FLOLS is helpful for glideslope control but is less than optimum (Brictson, 1967; Perry, 1968). An improved FLOLS display has been tested in the Visual Technology Research Simulator (VTRS) (Kaul, Collyer and Lintern, 1980). In the new display, vertical, variable length bars were used to add a rate-lead (first-order) component to the existing displacement (zero-order) information provided by the meatball of the conventional FLOLS. The meatball was retained in its conventional configuration. The variable length bars were driven by a signal that was proportional to the difference between the current descent rate and a desired descent rate based on current displacement from the glideslope. This new FLOLS configuration was designated the COMMAND display, with the variable length bars being referred to as Descent Rate Cuing (DRC).

A simulator evaluation showed that the approach performance with the COMMAND display was more stable and accurate than with the CONVENTIONAL display. The RMS error scores and standard deviations for the COMMAND display were 40% to 50% better than those for the CONVENTIONAL display (Kaul, et al., 1980). Although the results of that study were encouraging,

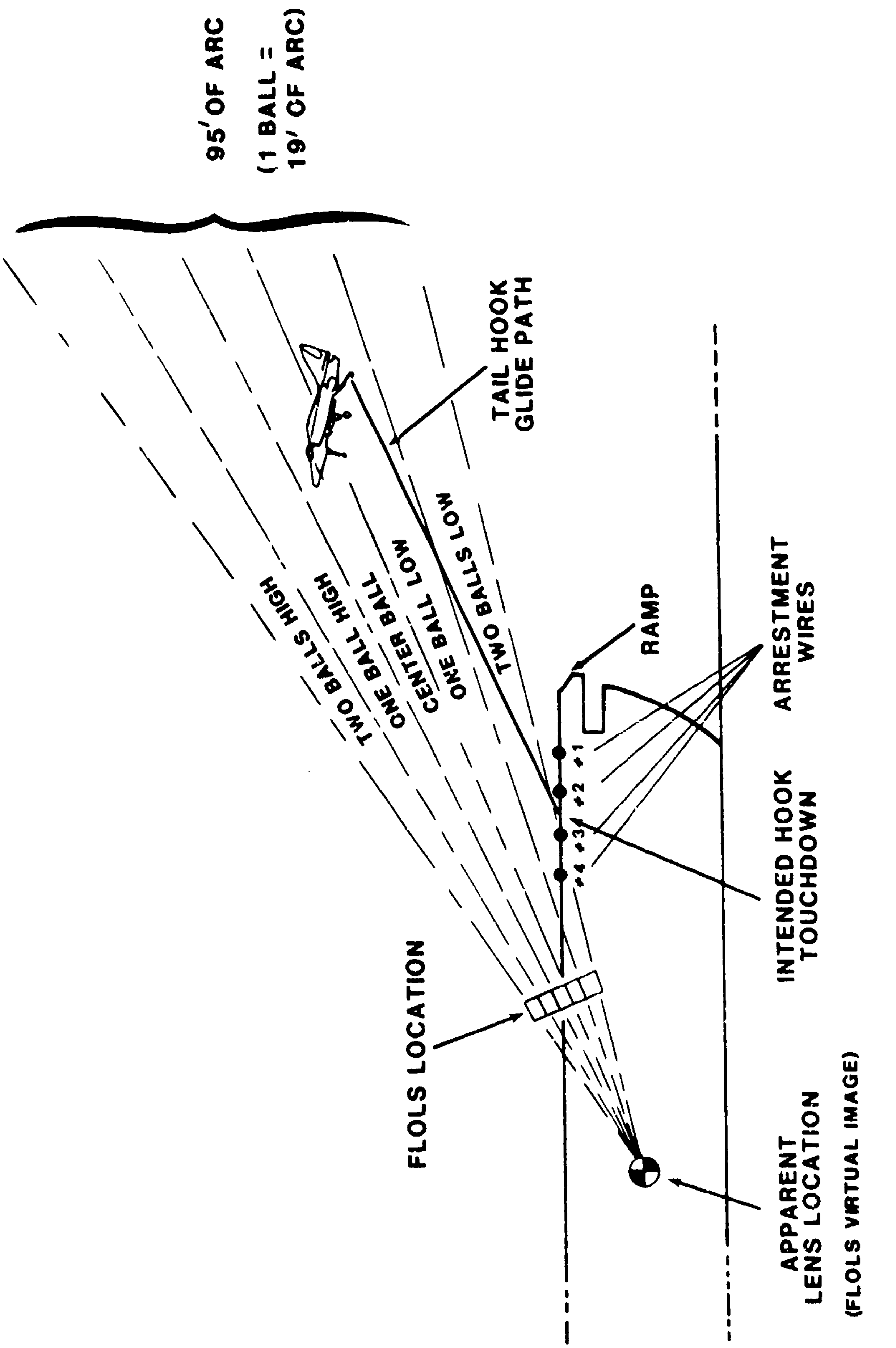

FIGURE 1: CARRIER APPROACH SCHEMETIC DEPICTING FLOLS ENVELOPE. TAIL HOOK GLIDEPATH, AND ARRESTMENT WIRE LOCATIONS.

the COMMAND display is a prototype system and, as such, requires further testing to establish its value under various conditions. This report describes two experimental investigations of the new system.

SECTION II

INTRODUCTION - EXPERIMENT 1

The Kaul, et al. (1980) study showed that the improvement in performance with the COMMAND display tended to be less substantial near the ramp. It appeared that the COMMAND display did not provide sufficient indication of descent rate close to the ship. Sensitivity of the arrows had been chosen to provide appropriate indications for typical pilot control inputs near the middle of the approach. It became apparent that the DRC gain was insufficient during the last 500 ft. of the approach and that a significant error could develop with no or very little indication from the DRC. The DRC gain used by Kaul, et al. (1980) was linear (equal displacement in feet and linear rate errors in ft/sec produced equal DRC indications throughout the approach). An angular gain (equal angular deviations and angular rate errors produced equal DRC indications throughout the approach) would produce a more sensitive display near the ramp with the added advantage of making the system independent of aircraft range which has typically been difficult to measure passively with sufficient accuracy. Thus a DRC algorithm incorporating an angular gain was tested.

Of particular interest was the probability that aircraft with significantly different glideslope characteristics would require specifically tailored DRC algorithms to optimize performance gains with the DRC. The T-2 simulation software was modified to produce aircraft vertical path response characteristics that approximated the A-7 (currently used in the Fleet) and the F-18 (to be introduced into the Fleet). The three aircraft types were tested in the experiment.

A problem that might be encountered with the new display is that of noise on the first-order display resulting from limited resolution of sensors used to track the approaching aircraft. A random forcing function was superimposed on the COMMAND signal to test the effects of display noise on approach performance. In anticipation of the noisy signal disrupting approach performance, one possible solution was tested, that being to activate the DRC only at the aircraft ranges close enough to allow reasonable tracking resolution. DRC onset ranges of 1500, 3000 and 6000 feet were used.

The difficulty of landing on carriers is accentuated at night. The modified FLOLS might substantially affect night performance, thus a time-of-day factor was included in the experiment.

SECTION III

METHOD - EXPERIMENT 1

SUBJECTS

Six experienced carrier qualified Navy pilots made carrier landings in a flight simulator at the Naval Training Equipment Center (NAVTRAEQUIPCEN). Table 1 summarizes the flight experience of the pilots.

APPARATUS

The Visual Technology Research Simulator (VTRS) described elsewhere by Collyer and Chambers (1978), consists of a fully instrumented T-2C Navy jet trainer cockpit, a six degree-of-freedom synergistic motion platform, a 32-element G-seat, a wide angle visual system that can project both computer-generated and model-board images, and an Experimenter/Operator Control Station. The motion system, G-seat and model board were not used in this experiment.

AIRCRAFT TYPES. The VTRS normally simulates the flight characteristics of a T-2C. Some characteristics of the mathematical model were modified so that the simulation would resemble the path response characteristics of current Navy tactical aircraft. Two other aircraft path responses were simulated; one resembling the F-18 and the other resembling the A-7. Details of the modifications to the T-2C simulation are presented in Ringland (1981). Major changes included thrust moment, thrust lag, lift-curve slope and drag modifications. The short period aircraft response was not modified.

All three simulations were flown in the experiment. The T-2C simulation was flown with full flaps and 10,000 lbs. gross weight to give an approach speed slightly less than 100 knots. The other two simulations were flown with half flaps and 11,850 lbs. gross weight to give an approach speed of 127 knots.

VISUAL SYSTEM. The background subtended 50° above to 30° below the pilots' eye level, and 80° to either side of the cockpit. The carrier image, which was a representation of the Forrestal (CVA 59), was generated by computer and projected onto the background through a 1025-line video system. A carrier wake and FLOLS were also generated by this method. Both daytime and nighttime carrier images could be displayed (Figures 2 and 3).

Average delay between control inputs and generation of the corresponding visual scene was approximately 117 msec. Calculation of new aircraft coordinates required 50 msec while calculation of the coordinates for the visual scene corresponding to the viewpoint from the new aircraft coordinates required approximately 50 msec. Generation of the new scene required 17 msec. An updated visual scene was displayed every 33 msec.

TABLE 1. BIOGRAPHICAL DATA ON PILOT SUBJECTS

Subject #	1	2	3	4	5	6
Age	27	36	27	33	38	34
Flight Hours (Military)						
Aircraft	1020	3050	1500	2250	2900	2600
Simulator	5	15	200	100	50	100
Last 30 Days Hours/Aircraft	50/ T-2C	0	35/ S3	10/ A7	0	0
Number of Carrier Landings						
Total	55	680	130	250	250	200
Last 12 Months	10	0	20	6	50	34
Last 30 Days	2	0	0	0	0	0

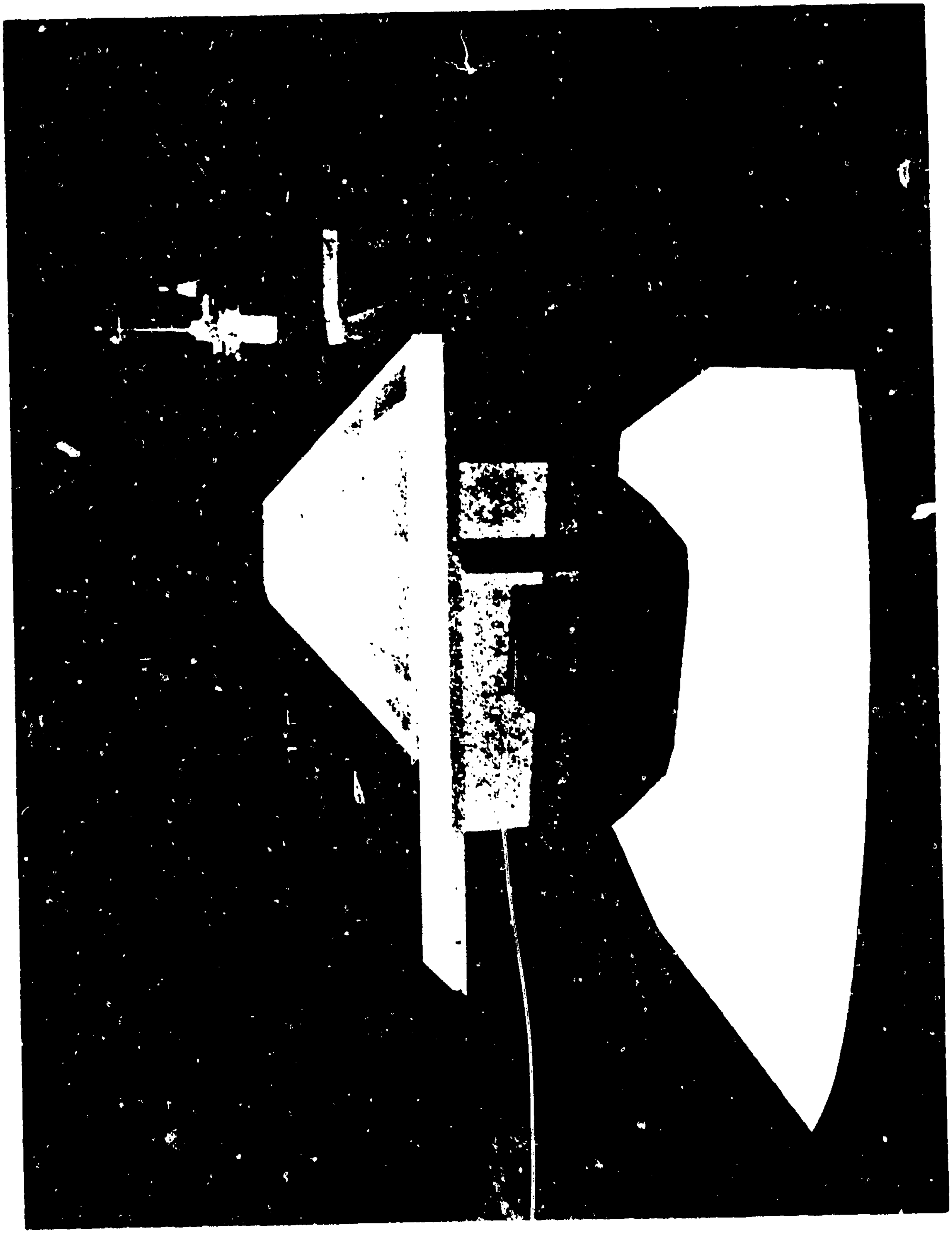

Figure 2. Computer-Generated Image of the Day Carrier, with FLOLS and Portion of Wake.

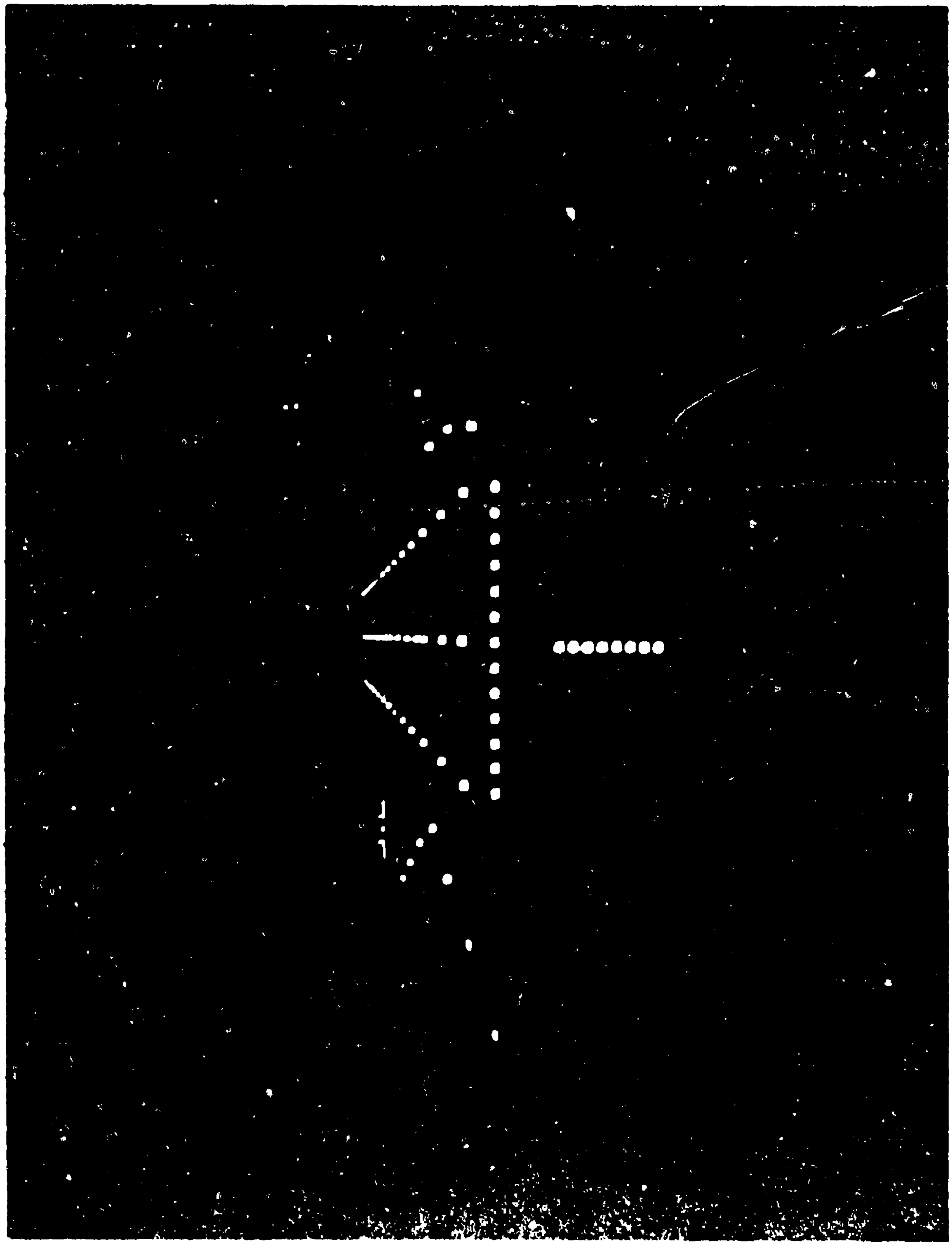

Figure 3. Computer-Generated Image of the Night Carrier with FLOLS.

The sky brightness for the Day scene was 0.85 fL (foot-Lambert) and the seascape brightness was 0.6 fL. The brightest area of the Day carrier was 4.0 fL. Except for the horizon there were no features represented in either the sky or sea. The Night background luminance was 0.04 fL and the horizon and seascape were not visible. The Night carrier appeared as lights of .8 fL brightness outlining the landing deck and other features.

FRESNEL LENS OPTICAL LANDING SYSTEM. The configuration of the FLOLS is shown in Figure 4. In contrast to a carrier FLOLS, which is generated by incandescent lights and can therefore be much brighter than other parts of the carrier, the simulated FLOLS was generated by the same system as the carrier image. It was therefore only as bright as the brightest areas of the ship (e.g., the white lines on the landing deck). To compensate for its lower relative brightness, the FLOLS was enlarged by a factor of 4.5 when the distance behind the ramp was greater than 2250 ft. From 2250 ft the size of the FLOLS was linearly reduced until it attained 1.5 times its normal size at 750 ft. It remained that size throughout the remainder of the approach. The FLOLS was centered 414 ft down the landing deck and 61 ft to the left of the centerline. It was set at a nominal 3.5° glideslope and with a lateral viewing wedge of 52°.

DRC MECHANIZATION. The first-order display components, depicted as rate-arrows on Figure 4, were driven by error signals proportional to the difference between the simulated aircraft's actual and computed optimum elevation angle rate of change with respect to the FLOLS. Elevation angle, θ_E, was defined as the angle subtended at the FLOLS virtual image by the aircraft slant range vector, r_L, and the projected FLOLS nominal glideslope beam (3.5° relative to the horizon), (see Figure 5 for nomenclature). For each update of the visual scene (frame), the length of the vertical arrows in scale feet, ℓ_a, was computed as:

$$\ell_a = \frac{r_F}{K_\theta}(\dot{\theta}_E - \dot{\theta}_C) \qquad (1)$$

where

r_F = 150 feet, the FLOLS virtual image distance.

$\dot{\theta}_E = \dfrac{(\theta_{E_i} - \theta_{E_{i-1}})}{\tau}\,\dfrac{2\pi}{360}$, (radians/sec.)

θ_{E_i} = current frame elevation angle (degrees),

$\theta_{E_{i-1}}$ = previous frame elevation angle (degrees),

τ = .033 sec., the computational sampling interval

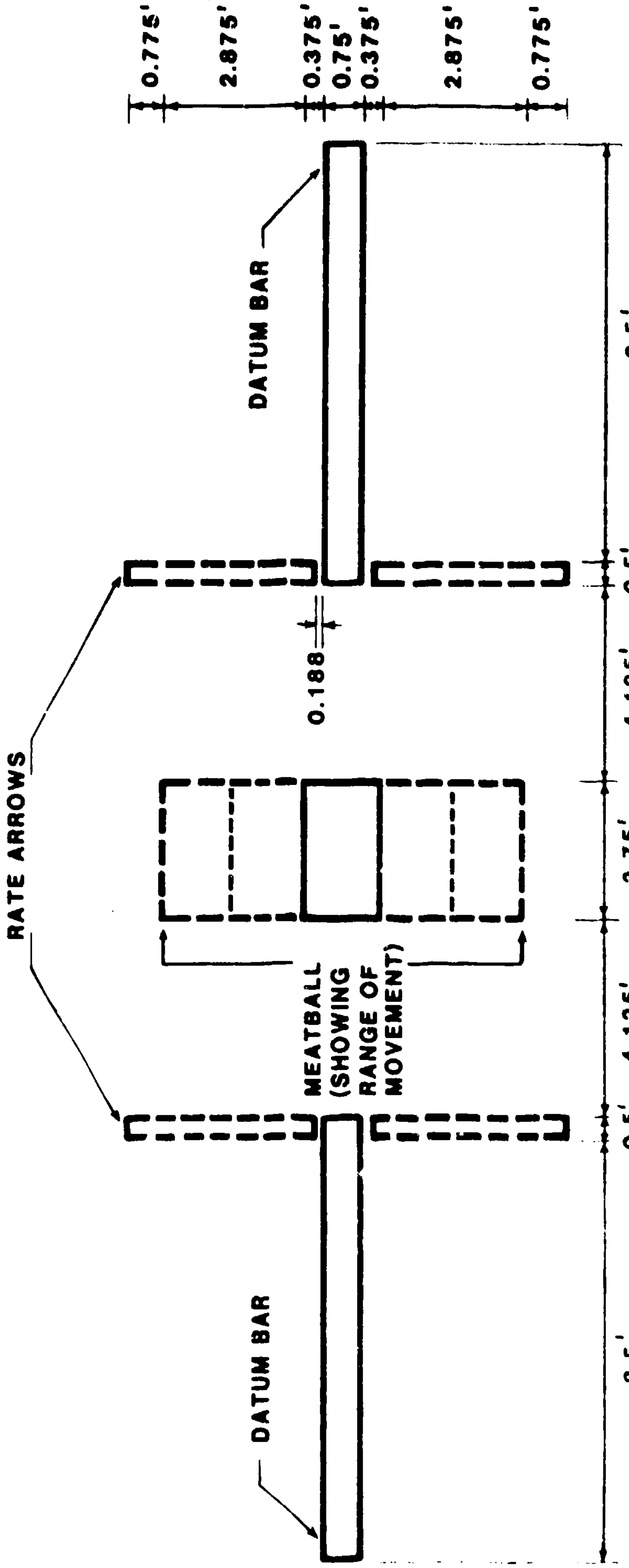

FIGURE 4: CONFIGURATION OF FLOLS SIMULATION, SHOWING DATUM BARS, RATE ARROWS, AND MEATBALL. (DIMENSIONS SHOWN ARE IN FT.)

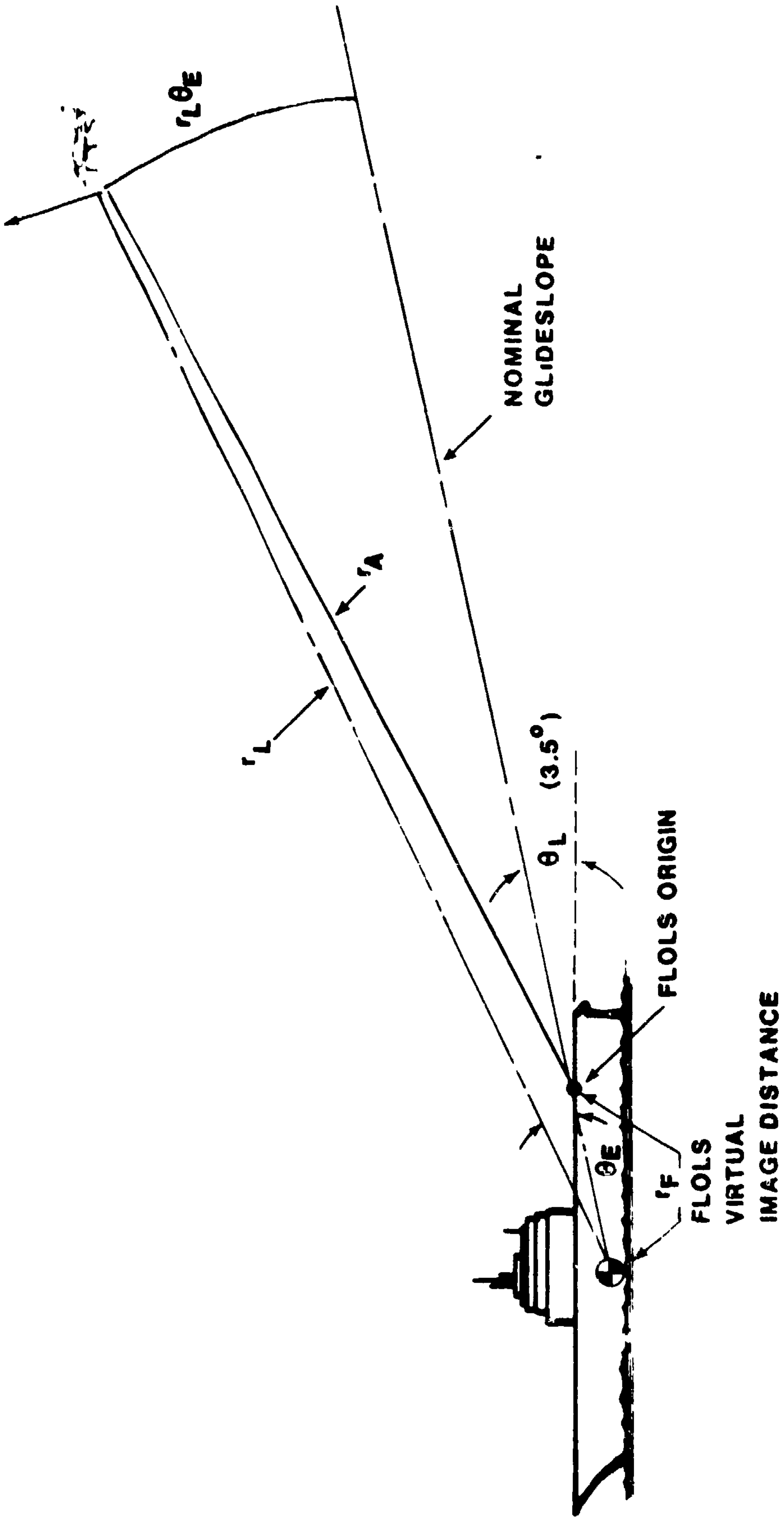

FIGURE 5: DRC DISPLAY NOMENCLATURE

and

$$\dot{\Theta}_C = -K_\Theta \, \Theta_{E_i} \frac{2\pi}{360} \text{ (radians/sec.)}$$

$$K_\Theta = \text{rate-lead time constant (sec.}^{-1}\text{).}$$

The effect of this mechanization was to provide first-order lead equivalent to:

$$T_{lead} = \left[K_\Theta - \frac{\dot{r}_L}{r_L} \right]^{-1} \text{ (sec.)} \qquad (2)$$

and to scale the gain of the rate-lead optical display to that of the basic FLOLS, i.e., inversely proportional to range. The DRC arrow length was equal to the apparent displacement of the meatball from the datum bars when the aircraft was flying a constant glideslope angle relative to the FLOLS (when $\dot{\Theta}_E = 0$). Based on an analysis in Ringland (1981), the lead equalization parameter K_Θ was adjusted for each aircraft as in Table 2.

TABLE 2. RATE-LEAD PARAMETERS

Simulated Path Response	K_Θ (Sec^{-1})
T-2	0.9
F-18	0.6
A-7	0.5

CUING ONSET. Four cuing conditions were used. One was a control condition in which the descent rate cues were not used at all. In the other three conditions the cuing indicators were activated at 6000, 3000, or 1500 ft from the ship. The cut lights were flashed for 4 seconds at the onset of the cuing.

DRC NOISE. A random forcing function of the form:

$$\Phi_i = \sum_{i=1}^{3} \left[A_i \sin (W_i \, T + \phi_i) \right] \qquad (3)$$

where A = Amplitude (ft.)
W = Frequency (Hertz)
T = Time from start of the trial (sec.)
ϕ = Phase angle (# cycles);

was applied to the vertical axis of the simulated carrier deck as ship heave in an attempt to imitate real ship motion compensation and servo induced noises. The component frequencies and their amplitudes are shown in Table 3. Phase relationships were randomly generated for the onset of each trial. These ship motions were summed and integrated into the derived elevation angle rate of change, thus appearing in the computed values of DRC magnitude (ℓ_{s}) and meatball displacement. These inputs appeared on the DRC indicators as high frequency noise.

It had been intended that the forcing function produce variations in DRC indicators that were within the pilots' tracking capabilities. The aim had been to produce a false component for the DRC signal that might mimic a false signal resulting from limited resolution of sensors used to track an aircraft. The frequencies that were actually used were too high and resulted in distracting noise component that was well outside the pilots' tracking capabilities. However the effects on performance of distracting or irrelevant DRC noise was thought to be of sufficient interest to retain the data from the noise trials for this report.

TABLE 3. SIMULATED NOISE PARAMETERS

Frequency (W, Hertz)	Amplitude (A, ft.)
0.100	2.252
0.225	2.380
0.350	1.122

TURBULENCE. Turbulence was represented by random forcing functions applied to the x, y, and z axes of the aircraft. The number of sine waves, their frequencies, and their relative amplitudes are shown in Table 4. Phase relationships were randomly generated for the onset of each trial

TABLE 4. PARAMETERS OF THE TURBULENCE MODEL

	Frequency (Hertz)	Amplitude (ft.)
Longitudinal	.020739	.206
	.062218	.240
	.145308	.227
	.228531	.175
	.352703	.151
Lateral	.133676	.914
	.4768[illegible]3	.086
Vertical	.041479	.443
	.103700	.218
	.159839	.143
	.269481	.111
	.373903	.085

SIMULATOR CONFIGURATION. The simulator was initialized with the aircraft at 9000 ft. from ramp, at 500 ft. altitude, on centerline, flying straight and level and in the approach configuration (hook and wheels down, speed brake out, 15 units Angle of Attack). A landing trial was flown from the initial condition to wire arrestment, or in the case of a bolter, to 1000 feet past the carrier.

The carrier was set on a heading of 360° at 20 knots. Environmental wind was set at 349.5° with a velocity of 5.4 knots. This combination of carrier speed and environmental wind produced a relative wind component of 25 knots down the landing deck. Turbulence was used on all trials to increase the difficulty.

PROCEDURE

All pilots flew 132 approaches over a four-day period (see Table 5). On their first day they were briefed on the purpose and conditions of the experiment. They were instructed in safety procedures for the simulator and in its features that did not represent aircraft functions. They then flew the simulator for five minutes without attempting to land. They completed their familiarization period with 24 approach trials using the first of the simulated aircraft types that they would use in the subsequent three days of experimental trials. During the practice session they flew day and night approaches, with and without sensor noise, and with the descent rate indicators either not present, or switching on at 6000 feet from the carrier.

TABLE 5. EXPERIMENTAL DESIGN

FAMILIARIZATION BLOCK

1-4	5-8	9-12	13-16	17-20	21-24
122	121	112	422	421	412

TRAINING TRIALS FOR EACH BLOCK

1	2	3	4	5	6	7	8	9	10	11	12
122	121	111	412	422	421	311	312	322	221	211	212

EXPERIMENTAL BLOCK #1 - SUBJECT #1

F-18										
1-12 (Training)	5 Mins.	13-15	16-18	19-21	22-24	5 Mins.	25-27	28-30	31-33	34-36
Different Condition Each Trial as above		111	122	212	221		312	321	411	422

FLOLS DRIVE AND ENVIRONMENTAL CONDITION SEQUENCES

SUBJECT #	BLOCK #	1	2	3
1	Aircraft Type	F-18	A-7	T-2
	Condition Codes	111 122 212 221 312 321 411 422	212 221 111 122 411 422 312 321	312 321 411 422 111 122 212 221
2	Aircraft Type	A-7	T-2	F-18
	Condition Codes	412 421 311 322 211 222 112 121	112 121 311 322 412 421 211 222	211 222 412 421 311 322 112 121
3	Aircraft Type	T-2	F-18	A-7
	Condition Codes	311 322 111 122 211 222 411 422	411 422 211 222 111 122 311 322	111 122 411 422 211 222 311 322
4	Aircraft Type	F-18	T-2	A-7
	Condition Codes	212 221 312 321 112 121 412 421	312 321 212 221 412 421 112 121	412 421 112 121 312 321 212 221
5	Aircraft Type	T-2	A-7	F-18
	Condition Codes	111 121 212 222 312 322 411 421	212 222 111 121 411 421 312 322	312 322 411 421 111 121 212 222
6	Aircraft Type	A-7	F-18	T-2
	Condition Codes	422 412 321 311 221 211 122 112	122 112 321 311 422 412 221 211	221 211 422 412 321 311 122 112

CONDITION CODES

DIGIT 1 (Onset of DRC)	DIGIT 2 (Heave)	DIGIT 3 (Time)
1 = 0 3 = 3000' 2 = 1500' 4 = 6000'	1 = ON (.5) 2 = OFF (0)	1 = Night 2 = Day

Pilots flew 36 approaches on each of the successive three days using a different aircraft type on each day. The first 12 approaches were to familiarize the pilot with the aircraft type to be tested in that session, and to familiarize them with the various experimental conditions. The last 24 trials were data trials. Conditions were changed after 4-trial sub-blocks. A five minute rest was allowed after each block of 12 trials.

PERFORMANCE MEASUREMENT AND DATA ANALYSIS

Parameters of aircraft position were sampled at 30 Hz and used to derive altitude and lineup error scores from the desired approach path. Root Mean Square (RMS) error, mean algebraic error (bias) and variability around that mean were calculated for these two dependent variables over four equal segments of the final 6000 feet of the approach. Because the trends obtained with the two types of dependent measures were generally similar, RMS error scores were used to illustrate the results. These scores were partitioned into bias and variability components where it was necessary to examine the data in more detail.

Altitude and lineup errors at 4500, 3000, 2000, 1000 and 0 feet from the ramp were used to derive means and standard deviations at these five points in the approach across display conditions. Distance down the deck, distance from the centerline and descent rate were measured at touchdown, and the Landing Performance Score (LPS) (Brictson, Burger & Welfeck, 1973) was calculated. The LPS is a score assigned to each pass, ranging from 1.0 (technique waveoff) to 6.0 (#3 wire trap).

Repeated measures analyses of variance were used as the primary statistical test of trends in the data. Eta squared (η^2) was calculated to estimate the proportion of variance accounted for by reliable effects.

SECTION IV

RESULTS - EXPERIMENT 1

RMS glideslope error was reliably lower for the 6000 feet onset in the 6000-to-4500 feet approach segment, than for the remaining three onset conditions (Table 6). No other reliable onset effects were observed.

RMS glideslope error was consistently smaller for day than for night approaches throughout the final 6000 feet of the approach, and this trend failed to achieve statistical reliability only with the 3000-to-1500 feet segment (Table 6). Reliable time-of-day by DRC noise interactions throughout the approach indicated that this may have been at least partially due to the DRC noise. Means of RMS glideslope for that interaction show the poorest performance on approaches at night without DRC noise (Table 7). By partitioning the RMS error into its bias and variability components, it was shown that pilots tended to fly lower approaches at night without DRC noise than with the other three time-of-day and DRC noise combinations (Table 7). RMS lineup errors were smaller with night than with day approaches (Table 8). By partitioning the RMS error into its bias and variability components, it was shown that pilots consistently flew day approaches to the right of the centerline (Table 9).

RMS lineup error was smaller with DRC noise than without it early in the approach (Table 8). In addition, pilots tended to land slightly further to the left of the centerline, and with a slightly higher descent rate with DRC noise (Table 10).

TABLE 6. GLIDESLOPE RMS ERROR (IN FEET): MEANS, STATISTICAL RELIABILITIES (*:p<.05, **:p<.01), AND VALUES OF ETA SQUARED (η^2)

Distance From the Ramp (Ft)	6000 - 4500	4500 - 3000	3000 - 1500	1500 - 0
Means				
FLOLS Onset				
0	18.58	14.46	10.88	6.34
1500	17.51	12.11	9.91	6.58
3000	18.52	13.95	9.75	6.62
6000	15.90	13.69	9.08	5.83
Time-of-Day				
Night	19.92	14.91	10.40	7.20
Day	15.34	12.19	9.41	5.49
DRC Noise				
On	16.38	13.04	9.91	6.55
Off	18.88	14.06	9.89	6.14
Aircraft				
A-7	19.63	15.85	11.16	7.21
F-18	17.15	12.41	9.10	5.84
T-2	16.11	12.40	9.45	5.97

Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
FLOLS Onset (O)	*	.009	--	--	--	--	--	--
Time-of-Day (T)	**	.025	**	.025	--	--	**	.051
DRC Noise (N)	--	--	--	--	--	--	--	--
Aircraft (A)	*	.016	*	.017	--	--	**	.027
OT	--	--	--	--	--	--	--	--
OH	--	--	--	--	--	--	--	--
OA	--	--	--	--	--	--	--	--
TN	**	.015	*	.010	*	.011	**	.029
TA	--	--	--	--	--	--	--	--
NA	--	--	--	--	--	--	--	--

TABLE 7. GLIDESLOPE RMS, AVERAGE, AND VARIABILITY ERROR (IN FEET): MEANS OF TIME-OF-DAY BY DRC NOISE INTERACTIONS

Distance From the Ramp (Ft)	6000 - 4500	4500 - 3000	3000 - 1500	1500 - 0
<u>Glideslope RMS Error</u>				
Noise x Night	16.79	13.18	9.84	6.76
No Noise x Night	23.04	16.65	10.96	7.63
Noise x Day	15.96	12.91	9.98	6.33
No Noise x Day	14.72	11.47	8.83	4.64
<u>Glideslope Average Error</u>				
Noise x Night	-3.56	0.12	-0.17	-3.45
No Noise x Night	-8.94	-4.27	-0.55	-4.77
Noise x Day	-3.21	2.22	4.03	-2.85
No Noise x Day	-5.75	3.08	3.41	-1.88
<u>Glideslope Variability Error</u>				
Noise x Night	5.84	5.06	4.57	3.67
No Noise x Night	6.09	6.81	5.52	3.31
Noise x Day	6.76	5.83	5.22	3.36
No Noise x Day	6.47	5.27	4.35	2.53

TABLE 8. LINEUP RMS ERROR (IN FEET): MEANS, STATISTICAL RELIABILITIES (*:p<.05, **:p<.01), AND VALUES OF ETA SQUARED (η^2)

Distance From the Ramp (Ft)	6000 - 4500	4500 - 3000	3000 - 1500	1500 - 0
Means				
FLOLS Onset				
0	26.40	23.72	16.07	7.10
1500	27.91	22.37	13.59	7.06
3000	23.70	20.62	14.48	7.86
6000	27.56	25.58	16.54	6.99
Time-of-Day				
Night	23.72	19.04	13.87	7.61
Day	29.06	27.10	16.46	6.89
DRC Noise				
On	24.07	20.55	14.95	7.25
Off	28.72	25.60	15.39	7.25
Aircraft				
A-7	25.00	22.27	15.90	7.34
F-18	24.64	22.56	14.29	6.52
T-2	29.53	24.39	15.32	7.89

Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
FLOLS Onset (O)	--	--	--	--	--	--	--	--
Time-of-Day (T)	*	.010	**	.038	**	.018	--	--
DRC Noise (N)	**	.024	**	.028	--	--	--	--
Aircraft (A)	--	--	--	--	--	--	--	--
OT	--	--	--	--	--	--	--	--
OH	*	.008	--	--	--	--	--	--
OA	--	--	--	--	--	--	--	--
TN	**	.016	--	--	--	--	--	--
TA	*	.014	--	--	--	--	**	--
NA	--	--	--	--	--	--	--	--

TABLE 9. LINEUP AVERAGE AND VARIABILITY ERROR (IN FEET): MEANS FOR TIME-OF-DAY

Distance From the Ramp (Ft)	6000 - 4500	4500 - 3000	3000 - 1500	1500 - 0
Lineup Average Error				
Night	.669	-1.082	-3.176	-.237
Day	24.059	22.760	8.900	-.134
Lineup Variability Error				
Night	6.379	5.530	5.485	3.732
Day	4.305	4.996	6.468	3.228

Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
Lineup Average Error								
Time-of-Day	**	.14	**	.20	**	.11	--	--
Lineup Variability Error								
Time-of-Day	**	.06	--	--	*	.013	*	.012

TABLE 10. TOUCHDOWN SCORES:
MEANS, STATISTICAL RELIABILITIES
(*:p<.05, **:p<.01), AND VALUES
OF ETA SQUARED (η^2)

	LPS	Distance Down Deck (Ft.)	Distance From Centerline (Ft.)*	Descent Rate (Ft Per Sec.)
Reference Values for Ideal Approach	6.0	194.5	0	See Note Below†
Means				
FLOLS Onset				
0	3.47	154.17	-2.71	9.89
1500	3.58	141.97	-1.87	9.64
3000	3.88	158.17	-2.41	9.67
6000	3.85	155.07	-2.18	10.13
Time-of-Day				
Night	3.55	149.37	-1.77	10.03
Day	3.84	155.31	-2.81	9.63
DRC Noise				
On	3.56	151.42	-2.84	10.33
Off	3.83	153.26	-1.75	9.34
Aircraft				
A-7	3.46	153.22	-1.71	10.46
F-18	3.92	155.43	-2.74	11.18
T-2	3.70	148.38	-2.43	7.85

Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
FLOLS Onset (O)	--	--	--	--	--	--	--	--
Time-of-Day (T)	--	--	--	--	*	.010	--	--
DRC Noise (N)	--	--	--	--	*	.011	**	.028
Aircraft (A)	--	--	--	--	--	--	**	.23
OT	--	--	--	--	--	--	--	--
ON	--	--	--	--	--	--	--	--
OA	--	--	--	--	**	.038	--	--
TN	--	--	--	--	--	--	--	--
TA	--	--	--	--	--	--	--	--
NA	--	--	--	--	*	.018	--	--

* + = Right
†T-2 = 8.58, A-7 and F-18 = 10.50 (Average = 9.86)

SECTION V

DISCUSSION - EXPERIMENT 1

The change from a linear DRC gain in the first study (Kaul, et al. 1980) to an angular DRC gain seems to have diminished the value of the indicators to such an extent that they barely aided glideslope control. The only noticeable benefit was early in the approach and even then the effect was small (accounting for 1% of the variance versus 10% in the first study). The first study indicated some loss of effect near the ramp and this fact, together with a discussion by Durand (1967) on pilot behavior in the carrier landing task, suggested that the DRC sensitivity should be compatible with the meatball sensitivity. Thus a constant angular sensitivity that, in relation to the first study, decreased sensitivity far from the ramp but increased it near the ramp, was selected.

In retrospect it now appears that tight glideslope control is contingent on the pilot obtaining good rate information from the FLOLS, and that the success of the earlier algorithm was largely due to the fact that the DRC provided good rate information before it was available from the meatball. Only when the aircraft is close to the carrier, and the meatball moves relatively quickly in response to departures from the glideslope, can the pilot acquire first-order information from a conventional FLOLS (Durand, 1967). At its inception the DRC had been viewed as a system that added first-order information to the zero-order information provided by the conventional FLOLS. The data now at hand suggest that it should be considered as a system to compensate for the pilots' inability to derive first-order information from the meatball movement. Thus sensitivity of the DRC should be more critical far from the carrier where the meatball indication is insensitive. Thus a linear gain, as used in Kaul et al. (1980), but possibly higher and with some non-linear adjustment towards the end of the approach, would appear to be better.

Time of day had an effect on both glideslope and lineup errors. The effects on glideslope were unexpected in that they were not found in the previous study. The interactions of display noise with time of day for glideslope errors suggest that the DRC noise provided an influence on glideslope tracking that did not exist in the Kaul et al. (1980) study. Clues for the source of the effect were sought by examining the cell means of RMS glideslope error for the two-way interaction of display noise by time of day, and then partitioning these means into their bias and variance components. A tendency for Night approaches without DRC noise to be flown lower than for the remaining combinations appear to have influenced the RMS glideslope error for that condition. However it is difficult to suggest why this combination of conditions should result in lower approaches.

The lineup errors were consistent with those found in the previous study, and of a similar magnitude. The cause for the bias to the right

during Day approaches remains obscure, but as noted in the previous study, it has been observed with shipboard day and clear visibility night recoveries (Brictson, 1966). The effects of DRC noise on early RMS lineup error and on lateral error at touchdown are also difficult to explain, particularly in view of the fact that it has no clear effect on RMS glideslope error, a dimension that it could have been expected to affect. Its effect on descent rate at touchdown might suggest less stable behavior close-in where the main effects seem to become severe. However the DRC noise effects appear to be too weak and inconsistent to offer any clear insights.

The aircraft main effect showed greater RMS glideslope errors for the A-7 approximation. This finding was an expected result of increasing the thrust lag for the A-7 approximation and tended to validate that change. The primary purpose of simulating different aircraft types was to ascertain whether the DRC had similar facilitating effects across a range of aircraft. Given the failure in this experiment for the DRC to have any consistent facilitating effect, this question remains untested.

SECTION VI

INTRODUCTION - EXPERIMENT 2

The clearest implication from the comparison of linear and angular gains for the DRC system is that the gain can be critical. An appropriate gain can produce a strong and consistent improvement in glideslope control while an inappropriate one can substantially eliminate the beneficial effects of the DRC. The comparison of data from Kaul et al. (1980) and from Experiment 1 of this report clearly favors a linear system.

The Kaul et al. (1980) data suggest that as the pilot nears the ramp (approximately 1000 feet from it) a higher gain than used in that experiment would be optimum and further consideration of the problem suggests that a higher gain throughout most of the approach might be desirable. However it was thought that the higher gain might encourage inappropriate corrective behavior if errors were indicated in the final three seconds of the approach where it is too late to make safe and effective glideslope corrections. Thus an algorithm that maintained an approximately liner gain (higher than used by Kaul et al., 1980) throughout most of the approach with a sharp drop commencing at approximately 550 feet from touchdown was programmed to drive the DRC.

SECTION VII

METHOD - EXPERIMENT 2

SUBJECTS

Four experienced carrier-qualified Navy pilots participated in the experiment. Three were test pilots from Patuxent River Naval Air Station and the fourth had gained extensive experience in the VTRS and with the DRC during development work for the DRC experiments. Except as outlined below, apparatus, procedures, and data analyses were as for Experiment 1.

PROCEDURE

Three cuing onset conditions (0, 3000, and 6000 feet from the carrier) were fully crossed with Time-of-Day (Day, Night) over 12 trials (two per condition), with the conditions being systematically counterbalanced for trend. The A-7 approximation from Experiment 1 was used in Experiment 2.[1]

DRC MECHANIZATION. For this experiment the length of the DRC arrows, ℓ_a, was:

$$\ell_a = 0.7\, G_a\, r_L \left[\dot{\Theta}_E - \dot{\Theta}_C\right] \quad \text{(ft)} \tag{4}$$

where r_L, r_F, $\dot{\Theta}_E$ and $\dot{\Theta}_C$ were computed or defined as in Experiment 1 (see Figure 5)

and

$$G_a = \left| \frac{r_A - r_{TD}}{r_A + r_F} \right| \text{; arrow gain function,}$$

r_A = slant range from FLOLS origin to aircraft (ft)

r_{TD} = 50 ft; bias range from FLOLS origin to aircraft at which gain vanishes.

This again provided first-order lead equivalent to:

$$T_{lead} = \left[K_{\Theta} - \frac{r_L}{r_L}\right]^{-1} \quad \text{(sec).} \tag{5}$$

---

[1]The experiment was limited, particularly in number of trials, primarily because it was planned at short notice to exploit the unexpected and brief availability of the pilot subjects who had visited the VTRS facility to gain experience with the DRC before field and carrier trials.

However, the overall gain of this rate presentation remained essentially constant with range from DRC onset to approximately 550 feet from touchdown, then decreased sharply according to the computed value of G_a to a touchdown value of roughly one-half the initial gain. This gain schedule provided relatively high rate sensitivity when the corresponding FLOLS meatball position sensitivity was low (i.e., at long range) and reduced rate sensitivity at shorter ranges (within 550 feet from touchdown) when lead information can be reasonably well determined from the FLOLS (Durand, 1967).

DATA ANALYSIS. In view of the limited statistical power resulting from the small number of trials, overall glideslope η^2 was calculated for unreliable as well as reliable onset effects. The three possible pairwise comparisons for onset effects were calculated with the Tukey W Procedure (Ott, 1977).

SECTION VIII

RESULTS - EXPERIMENT 2

RMS glideslope error was consistently lower for the 6000 feet onset throughout the approach but only statistically reliable along the middle segments (4500 to 3000 feet and 3000 to 1500 feet) of the approach (Table 11). There were no other reliable effects for glideslope error.

There were no statistically reliable effects for lineup RMS error, although in contrast to previous data, it tended to be lower for Day than for Night approaches (Table 12). There was a time-of-day effect on lineup bias with pilots tending to fly further to the right during Day approaches than during Night approaches (Table 13).

TABLE 11. GLIDESLOPE RMS ERROR (IN FEET): MEANS, STATISTICAL RELIABILITIES (* :$p<.05$, ** :$p<.01$), AND VALUES OF ETA SQUARED (η^2)

Distance From the Ramp (ft)	6000 - 4500		4500 - 3000		3000 - 1500		1500 - 0	
Means								
FLOLS Onset								
0	25.29		16.24		11.02		6.47	
3000	29.32		23.47		16.42		6.06	
6000	18.19		9.56		7.78		4.53	
Time of Day								
Day	23.21		17.69		12.48		5.45	
Night	25.33		15.16		11.01		5.93	
Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
FLOLS Onset (O)	--	.08	**	.30	**	.26	--	.07
0 vs 3000	--	--	--	--	*	.10	--	--
0 vs 6000	--	--	--	--	--	--	--	--
3000 vs 6000	--	--	**	.30	**	.26	--	--
Time-of-Day (T)	--	--	--	--	--	--	--	--
OT	--	--	--	--	--	--	--	--

TABLE 12. LINEUP RMS ERROR (IN FEET): MEANS, STATISTICAL RELIABILITIES (* :p<.05, ** :p<.01), AND VALUES OF ETA SQUARED (η^2)

Distance From the Ramp (ft)	6000 - 4500	4500 - 3000	3000 - 1500	1500 - 0
Means				
FLOLS Onset				
0	26.39	19.07	13.39	8.19
3000	21.53	17.23	13.33	7.18
6000	23.54	19.16	12.12	9.04
Time of Day				
Day	20.45	14.83	10.55	7.59
Night	27.19	22.15	15.35	8.68

Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
FLOLS Onset (O)	--	--	--	--	--	--	--	--
Time-of-Day (T)	--	--	--	--	--	--	--	--
OT	--	--	--	--	--	--	--	--

TABLE 13. FOR AVERAGE LINEUP ERROR:
MEANS TIME OF DAY, STATISTICAL RELIABILITIES
(* :p<.05, ** :p<.01), AND VALUES
OF ETA SQUARED (η^2) (+ = RIGHT)

Distance From the Ramp (Ft)	6000 - 4500		4500 - 3000		3000 - 1500		1500 - 0	
Means								
Time of Day								
Day	16.08		- 0.43		.12		1.07	
Night	-5.17		-12.20		-9.8		-3.91	
Reliabilities and η^2	P	η^2	P	η^2	P	η^2	P	η^2
Time-of-Day (T)	**	.14	--	--	*	.13	*	.08

SECTION IX

DISCUSSION - EXPERIMENT 2

The trends in the data were consistent in magnitude and direction with those of Kaul et al. (1980), but few of them were statistically reliable. This is not surprising in that the limited number of trials severely limited the power of the statistical tests to demonstrate the reliability of real differences. While the results cannot be considered as conclusive, they can be used as a basis for developing a more powerful empirical test.

The DRC with onset at 6000 feet consistently reduced glideslope error throughout the approach in relation to the conventional FLOLS. Although the data do not suggest that the current algorithm is more or less effective than that used by Kaul et al. (1980), they do indicate that the problems found in the first experiment of this report have been overcome. The current gain schedule appears to be near optimum although a further empirical test to ascertain the best gain schedule may be worthwhile.

The 3000 feet onset for the DRC had been proposed as a means to give pilots use of the system even if it were too noisy early in the approach. The choice of 3000 feet was arbitrary in the sense that, once the concept had been tested, other onset ranges could be selected when the need became apparent. However the data indicate that onset partway through the approach disrupts performance. The DRC with 3000 feet onset was less effective than the conventional FLOLS. Consistent with these data was the frequent comment from the pilot subjects that onset partway through the approach was distracting.

The glideslope tracking differences between Day and Night approaches found in Experiment 1 of this report were not found in Experiment 2, thereby supporting the earlier conclusion that these differences resulted from the DRC noise signal. However the probable cause of this effect remains difficult to explain. In addition, it is not possible to rationalize the reversal in trend for RMS lineup error between Day and Night approaches.

REFERENCES

Brictson, C.A. Measures of pilot performance: Comparative analysis of day and night carrier recoveries. Santa Monica, CA: Dunlap & Associates, June, 1966.

Brictson, C.A. Analysis of F4 aircraft day and night carrier approaches. Aerospace Medicine, December, 1967, 38, 1219-1224.

Brictson, C.A., Burger, W.J., and Wulfeck, J.W. Validation and application of a carrier landing performance score: The LPS. Inglewood, CA: Dunlap & Associates, Inc., March, 1973.

Collyer, S.C., and Chambers, W.S. AWAVS, a research facility for defining flight trainer visual requirements. Proceedings of the Human Factors Society, 22nd Annual Meeting, Detroit, MI: 1978.

Durand, T.S. Carrier landing analysis. Hawthorne, CA: Systems Technology, Inc., STI TR 137-2, February, 1967.

Kaul, C.E., Collyer, S.C., and Lintern, G. Glideslope descent-rate cuing to aid carrier landings. Orlando, FL: Naval Training Equipment Center, NAVTRAEQUIPCEN IH-322, 1980.

Ott, L. An Introduction to Statistical Methods and Data Analysis. Massachusetts: Duxbury Press, 1977.

Perry, B.L. Optical guidance systems: Analysis, design and development. Naval Research Laboratory, Report 6581, 1967.

Ringland, R.F. Review of the NTEC T-2C landing simulator mathematical model, and its modification to a fleet-like fighter. In Jex, H.R., Jewell, W.F., and Ringland, R.F. Application of Control System Analysis Techniques to Pilot Performance and Training Research. Orlando, FL: Canyon Research Group, Inc., NAVTRAEQUIPCEN 78-C-0060-10, 1981.